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DETERMINATION OF MICROSCALE ROUGHNESS OF CYLINDRICAL  
SURFACES USING ULTRASONIC CREEPING WAVES

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ABSTRACT

The circumferential waves or creeping waves propagate in both media separated by a rough interface in an alternating fashion, and are reviewed from a theoretical point of view; the associated velocity of propagation dependence on the interface surface roughness is shown to be reasonably valid for microscale roughness determination. Experimental results are also included to support theory, and certain empirical relationships are derived as an example of the application of this technique.

INTRODUCTION

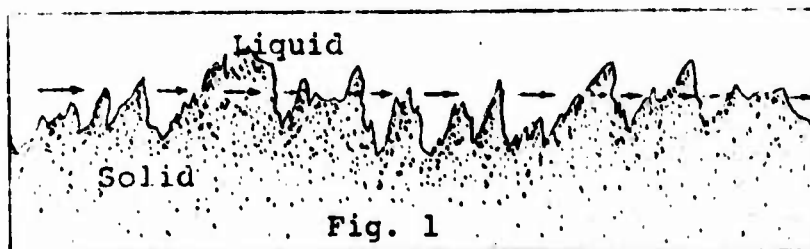
The roughness criterion<sup>1</sup> for random rough surfaces is expressed as:

$$\left[ \begin{array}{ll} \sigma > \lambda/8 \sin \theta & \text{for rough surfaces} \\ \sigma < \lambda/8 \sin \theta & \text{for smooth surfaces} \end{array} \right]$$

where  $\sigma$  = standard deviation of heights above and below the mean;  $\lambda$  = wavelength; and  $\theta$  = incident angle, and thus roughness is a relative measurement and depends exclusively on the incident wavelength " $\lambda$ " and the angle of incidence " $\theta$ ". Since in practice, actual measurement of microscale surface roughness on a relatively smooth surface is impossible, this paper offers a technique to obtain a measure of such microscale roughness in one manner.

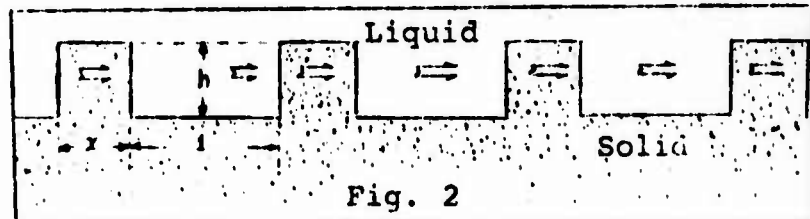
Experimental results<sup>2,3,4</sup> in combination with theoretical discussions<sup>5,6,7</sup> on the subject of circumferential waves on

cylindrical surfaces indicate that circumferential wave velocity vary with the incident wavelength. This, coupled with the fact that the creeping wave must traverse both media at the interface in a random manner, led to the conclusion<sup>9</sup> that this velocity should be a function of the interface roughness for a given wavelength. A physical interpretation of this phenomena is given in Fig. 1 where the surface wave is shown to propagate in both materials.

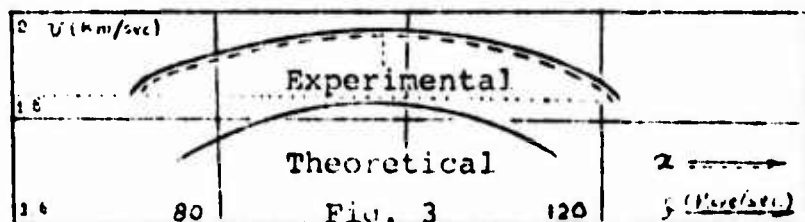


#### THEORY AND EXPERIMENT

The portion of the wave that propagates in the solid material (cylinder) is determined by the relative roughness of the surface. Figure 2 illustrates a model surface in which, for mathematical convenience, the height 'h' is fixed and 'x' is the variable. The variation of 'x' with respect to 'l' (both have the same units) represents the assumed roughness of the surface.



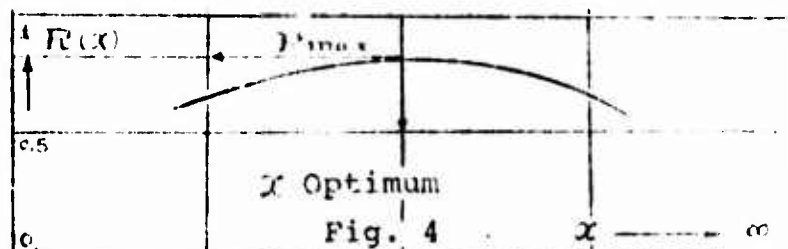
The experimental results and theoretical work show<sup>4</sup> that a maximum circumferential velocity is obtained at a certain optimum frequency while the velocity diminishes on both sides of the optimum frequency as Fig. 3 illustrates. One must also observe



the discrepancy between the theoretical and experimental curves; it can be explained by the fact that the roughness model is an idealized one; many other side effects are ignored for simplifying the illustration.

The above discussion shows that in order to determine the microscale roughness in terms of "x", the theoretical frequency versus velocity curves should be superimposed on the experimental curves. The value of "x optimum" for such a plot (see Fig. 3) corresponds to most of the propagation occurring in the solid and

hence the maximum circumferential velocity. It is further assumed that the maximum roughness corresponds to optimum  $x$  (see Fig. 4) implying that, in a first order model, roughness is proportional to the circumferential wave velocity.



Thus the experimental velocity may be related to  $x$  by the following equation:

$$\frac{x}{V_{\text{solid}}} + \frac{1}{V_{\text{fluid}}} = \frac{x+1}{V_{\text{exp}}} \quad (1)$$

or

$$\therefore x = \frac{V_{\text{solid}} (V_{\text{fluid}} - V_{\text{exp}})}{V_{\text{fluid}} (V_{\text{exp}} - V_{\text{solid}})} \quad (2)$$

These equations are valid for the model surface of Fig. 2. The apparent discrepancy between the experimental velocity vs.  $x$  curve and the Eq. (2), where  $x$  is a single valued function of  $V_{\text{exp}}$ , is due to the oversimplified surface model with constant  $h$ . In practice the surface roughness  $R$  is both a function of  $x$  and  $h$ :

$$R = R(x, h) \quad (3)$$

Hence it is possible to have a given roughness and the associated circumferential velocity for two different values of  $x$  and it requires a modification of Eq. (2) in order to account for the second order correction. However, for the simple case where  $h$  is a constant, Fig. 4 shows the complete agreement between theory and experimental results. For instance, as  $x$  approaches zero or infinity a smooth surface results (i.e.,  $R_{\text{min}}$ ) and the propagation through the solid is minimized and so is the magnitude of the circumferential wave velocity.

In an effort to include the  $h$  variation, it is assumed that  $h$  is a function of  $x$ , and the plot of velocity versus  $x$  (Fig. 3) is empirically modified from Eq. (1) to express its curvature as being the result of its elliptical shape whose center is  $(x_0, v_0)$  and whose semi-axes are  $a$  and  $b$  or

$$\frac{(x-x_0)^2}{a^2} + \frac{(v-v_0)^2}{b^2} = 1 \quad (4)$$

The information for the velocities in the solid and the fluid are contained in constants  $a$  and  $b$  since the plot of circumferential velocity versus frequency is unique for each material. Thus a specification of  $a$  and  $b$  as functions of the appropriate sound velocities, in each material, then for  $V_{\text{theoretical}}$ , Eq. (4) would yield  $x$ .

### CONCLUSIONS

The circumferential or creeping waves propagate in both materials forming an interface. The percent length of propagation path in each material is a function of the relative roughness  $R$  or the wavelength  $\lambda$ .

A first order microscale roughness criterion in terms of the measured circumferential wave velocity as a function of the frequency is offered as a useful tool for hitherto impossible to measure scale of roughness. Furthermore, a second order model involving second degree relationship between the surface height parameter and the roughness parameter is also proposed.

Moreover, experimental verification of the first order model is given for aluminum cylinder and advance work on this topic is under way at the University of Houston.

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